Early and Middle Jurassic

Two Early to Middle Jurassic sequences are known in Cuba (Fig. 8): one is the San Cayetano Formation of northern Pinar del Río Province, western Cuba, and the other is the Punta Alegre Formation known from four evaporite diapirs along the Cuban north coast (*see* legend, Fig. 11). The total age range of each unit is unknown. They may be of the same or of different ages. Their total thickness and geographic extent are unknown. Their bases have never been seen. Presumably the basal contacts are angular unconformities, particularly in southern Cuba, where pre-San Cayetano rocks are more severely metamorphosed.

These units assume great importance in the history of the Greater Antilles because they are the oldest definitely dated rocks within these islands. Therefore, beginning with Early-Middle Jurassic time, some reconstruction of the geological history and paleogeography of the Greater Antilles chain is possible.

SAN CAYETANO FORMATION

The San Cayetano Formation is exposed widely in the northern part of Pinar del Río Province, Cuba (Fig. 6). Metamorphosed equivalents may be present on the Isle of Pines, southern Cuba, and almost certainly are present just north of the Sierra de Trinidad, south-central Cuba. The Isle of Pines exposures resemble the San Cayetano (Kuman and Gavilán, 1965), but this correlation is not as convincing as that between the San Cayetano and its probable equivalent south of Manicaragua, Las Villas Province (Fig. 6). The area of metamorphic rocks in southeastern Oriente Province, easternmost Cuba (Fig. 6), also may have San Cayetano equivalents. Because the lithologic characteristics of the San Cayetano are unlike those of any other Cuban formation, lithologic similarity appears to be a reasonable basis for correlation of this formation on the island. Nevertheless, the suggested correlations are not proved; if they are correct, the San Cayetano is present in western, southern, and eastern Cuba.

The only dated sediments in the San Cayetano are in the type area, Pinar del Río Province. Here, probably near the top of the formation, are marine pelecypods of Bajocian-Bathonian (Fig. 9) to Callovian ages (Krömmelbein,

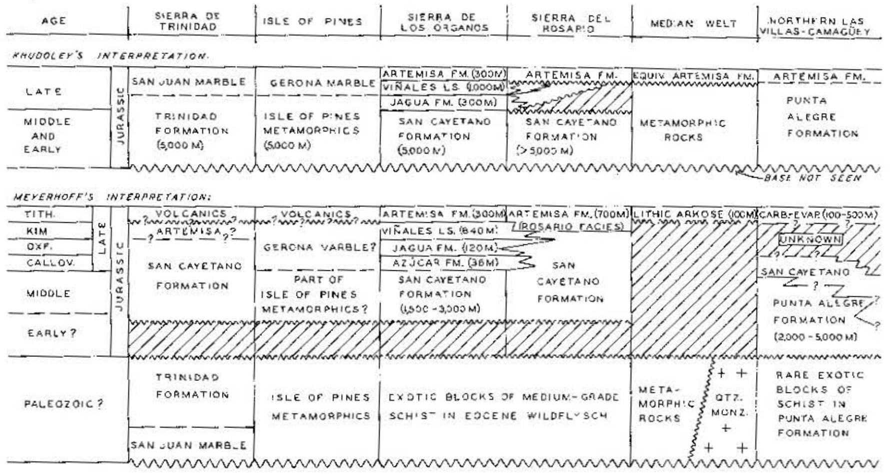

Figure 8. Khudoley's and Meyerhoff's different interpretations of pre-Cretaceous correlations, Cuba.

1956; Hatten, 1957; Imlay, 1964; Hatten and Meyerhoff, 1965). Several kilometers west of the type area near the Minas de Matahambre (Fig. 6), Vakhrameyev (Vachrameev) (1965, 1966) described abundant plant remains of *Phlebopteris cubensis* sp. nov. whose closest affinities are with Late Triassic to Late Jurassic phlebopterids in other parts of the world. Because this plant apparently is a new species, a more precise dating is not possible.

Therefore, it is possible that the San Cayetano has an age range of Late Triassic through Middle or early Late Jurassic. In the type area, it cannot be younger than late Oxfordian because definitely dated late Oxfordian marine sediments overlie the formation. Khudoley has assigned to the San Cayetano an Early-Middle Jurassic age, but Meyerhoff believes that the age may be entirely Middle to early Late Jurassic for reasons given subsequently.

East of the type area in the Sierra del Rosario, Artemisa (Tithonian) overlies the San Cayetano directly, and Hatten (June 10, 1968, written commun.) has suggested that the upper San Cayetano is equivalent to the lower part, or even most of the Viñales Limestone of northwestern Pinar del Río Province (Figs. 8, 16). If Hatten is correct, the upper part of the San Cayetano in the Sierra del Rosario area may be as young as earliest Tithonian.

The presence of San Cayetano elsewhere in the Greater Antilles is conjectural. The most likely areas where equivalents may be found are in the Plaine du Léogane, southeastern Haiti; Plaine du Nord, Massif du Nord, and Tortuga Island, northern Haiti; and the Samaná Peninsula, Dominican Republic (Figs. 7, 10, 11). Should the metamorphic rocks of these last-named areas be Early to Middle Jurassic, the existence of an elongate east-west basin on the present site of the Greater Antilles, prior to the establishment of the Late Jurassic-middle Eocene orthogeosyncline, is indicated.

The San Cayetano Formation, originally named the "Cayetano formation" by DeGolyer (1918), has no type section. Its type area is the vicinity of the

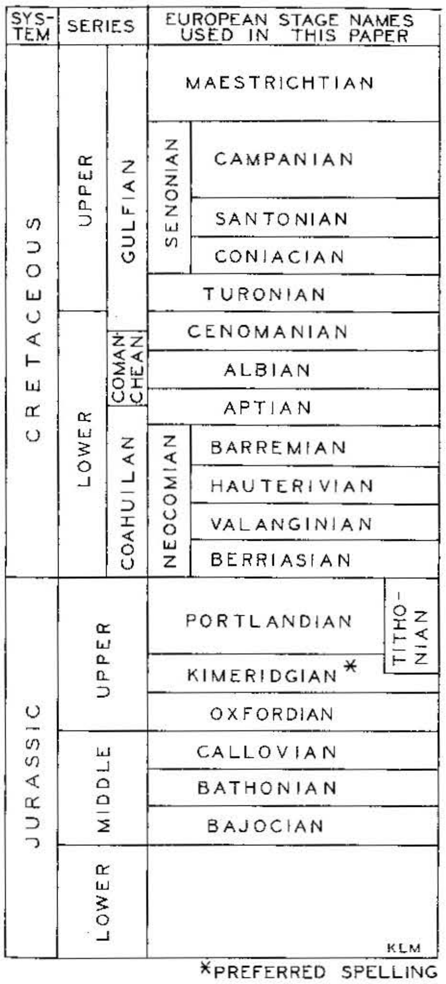

Figure 9. European stage names used in this paper. Kimeridgian is spelled with a single "m" because type locality is near Kimeridge, England (Arkell, 1956; and written commun., George V. Cohee, June 5, 1968).

village of San Cayetano, northern Pinar de Río Province (Fig. 6). The formation is a sequence of nonmetamorphosed to slightly metamorphosed (phyllitic), micaceous, black to dark-gray, carbonaceous shale, sandy shale, siltstone, and fine-grained sandstone (quartz wacke) with angular grains of quartz, plagioclase, and orthoclase. Quartz predominates. The formation weathers deep orange-brown, rust-brown, and brown. The slight metamorphism and abundant mica and sericite in many areas led J. Lewis (1932) and others to call the San Cayetano a schist ("Pinar schist") or phyllite. The sequence is well bedded. Beds are 1 to 20 cm thick and, together with the lithologic character, impart to the formation a very monotonous appearance.

Carbonized remains of plant stems are abundant. Only a few well-preserved plants have been found, and only a few marine beds are known. The dark color and the presence of pyrite suggest deposition in reducing conditions. Deposition in very shallow water is probable, and accumulation in fresh-water marshes is possible for parts of the formation. Deposition probably kept pace with subsidence and, at times, probably exceeded the subsidence rate.

Because of extreme structural complexity, the thickness is not known. Hatten and Meyerhoff (1965) and Hatten (1967, p. 782) reported a measured thickness of 1500 m in the Matahambre copper mine (Fig. 6). This is a minimum figure, and Hatten and Meyerhoff postulated a minimum total thickness of 3000 m. Khudoley believes that the thickness exceeds 5000 m. R. Palmer (1945) and others have suggested thicknesses in the order of 9000 to 10,000 m, but this estimate is at best a guess. Absence of marker beds, overturned sections, and numerous faults preclude accurate field measurements.

Rigassi (1963, p. 341) wrote that the San Cayetano greatly resembles the Jurassic-Neocomian Todos Santos Group of Guatemala. The San Cayetano is a dark-gray to black sequence; the Todos Santos is mainly continental red

beds. In the writers' opinion (Meyerhoff has mapped both sequences), there is no similarity. However, the San Cayetano does resemble the Jurassic El Plan Formation of Honduras (Carpenter, 1954; Mills and others, 1967).

PUNTA ALEGRE FORMATION

In northern Cuba, from the Habana-Matanzas boundary to northwestern Camagüey Province (Fig. 6), is an extensive Jurassic evaporite unit which Ducloz (1960) called the "San Adrián Formation" for exposures near the village of San Adrián, northwestern Matanzas Province. A. A. Meyerhoff and Hatten (1968) called this unit the "Punta Alegre Formation" elsewhere in Cuba because (1) the full range of lithologic types is not observed at San Adrián, Matanzas, and (2) the correlation of the "San Adrián" with the Punta Alegre is not proved by fossil control.

The Punta Alegre Formation, named by A. A. Meyerhoff and Hatten (1968) for the Punta Alegre diapir (Fig. 6), crops out only in salt domes, of which there are four in Cuba (Fig. 6, legend): three in northwestern Camagüey (Loma Cunagua, Isla de Turiguanó, and Punta Alegre) and one in northwestern Matanzas (San Adrián). Because of the salt-dome mode of occurrence, the thickness of the Punta Alegre is unknown. Solsona and Judoley (1964), reporting on the results of American, Dutch, Russian, and other seismic studies in northern Cuba, estimated that the depth to crystalline basement beneath northern Cuba is 8000 to 10,000 m, and that the depth to the Punta Alegre is at least 5000 to 6000 m. This leaves 2000 to 5000 m of section in which the Punta Alegre and associated sediments may occur.

The Sheridan and others map (*in* Drake, 1966, p. 43) shows the presence of about 11 km of post-basement (Paleozoic or Precambrian) strata in an east-west-trending basin centered on the Florida Keys. They called this the "South Florida-Andros Island basin." Although the basin is shown as closing and shallowing toward the southeast and east, the Solsona and Judoley (1964) data demonstrate that the basin depicted by Sheridan and others opens and deepens beneath northern Cuba and the south-central Bahamas. If one uses a figure of 2 km for the Tertiary thickness in the South Florida-Andros Island basin, and a 5-km thickness for the Late Jurassic and Cretaceous, 4 km of sediments remain to be accounted for. The writers believe that much of this thickness is the Punta Alegre Formation. It is significant that the seismic results from northern Cuba agree reasonably well with wholly independent data from southern Florida and the Bahamas.

Whether 2000, 4000, or 5000 m thick, it is doubtful that the entire interval is evaporite. Inclusions in the evaporite from the Tina Nos. 1 and 2 wells, Loma Cunagua diapir (Fig. 6), include red, gray, and maroon shale and brownish-red siltstone similar in appearance (except for the red beds) and composition to the San Cayetano. In the San Adrián diapir of northeastern Habana, Ducloz (1960) reported, in addition to blocks of post-salt formations, the presence of San Cayetano-like inclusions of micaceous sandy shale; medium-gray, medium- to coarse-grained, hard sandstone consisting of angu-

lar quartz, feldspar, and sericite; marble; and quartz-mica schist. Pyrite, tourmaline, and apatite crystals are disseminated throughout the diapir. The presence of the San Cayetano-like blocks suggests that the San Cayetano is associated in some way with the salt. However, because exotic blocks—even of basement-type rocks—occur in many salt diapirs in the world, it is not possible to determine the relations between the salt and the San Cayetano-type rocks (that is, whether the San Cayetano underlies, overlies, or is interbedded with the salt). Meyerhoff's interpretation is shown on Figure 11.

The approximate age of the Punta Alegre Formation has been determined on the basis of pollen and spores extracted from red silty shale inclusions in the Tina Nos. 1 and 2 wells by H. L. Cousminer (unpub. rept.; for summary, *see* A. A. Meyerhoff and Hatten, 1968, p. 327). According to Cousminer, the complete absence of angiosperm pollen, and the relatively great number and diversity of cycadophyte pollen with respect to the total recovery, almost certainly indicate a pre-Cretaceous, post-Permian age. If the Punta Alegre is correlative with the Louann Salt of the United States Gulf Coast, the age may be Rhaetian (latest Triassic) to Early or Middle Jurassic (Jux, 1961). Based on regional considerations, the writers favor an age assignment bracketed by the Rhaetian and Callovian (latest Triassic to early Late Jurassic) stages. The fact should be noted that this age is for the red silty shale inclusions, *not* for the salt.

GEOLOGIC RELATIONS BETWEEN SAN CAYETANO AND PUNTA ALEGRE FORMATIONS

The San Cayetano and metamorphosed San Cayetano equivalents are present in western, southern, and eastern Cuba. The Punta Alegre is present only in northern Cuba, close to the coast, from northeastern Habana Province to northern Camagüey Province. In the Jarahueca fenster (Fig. 6) of Hatten (1967), neither formation is present unless the basal lithic arkose below the Cretaceous carbonate and volcanic rocks is equivalent to both. The Jarahueca fenster is on a basement high which in Late Jurassic-middle Eocene time was an intrageosynclinal welt (Khudoley, 1967a) or "median welt."

There is no certainty that the two formations are equivalent as was assumed by Furrazola and others (1964, 1965), Hatten and Meyerhoff (1965), Khudoley (1967a), and A. A. Meyerhoff and Hatten (1968). Alternate correlation possibilities are considered in the next two sections.

PALEOGEOGRAPHIC RECONSTRUCTION BY KHUDOLEY

A major landmass or highland occupied the present site of the Caribbean Sea, and a depositional basin occupied the area of the Greater Antilles, the Bahamas, and part of southern Florida; a shallow-water evaporite basin was present on the site of the Gulf of Mexico (Fig. 10). Numerous rivers draining the Caribbean landmass flowed northward, carrying detritus to the present site of Cuba and possibly to Hispañola. The mineralogy of the San Cayetano clasts indicates that this landmass was composed predominantly of silicic

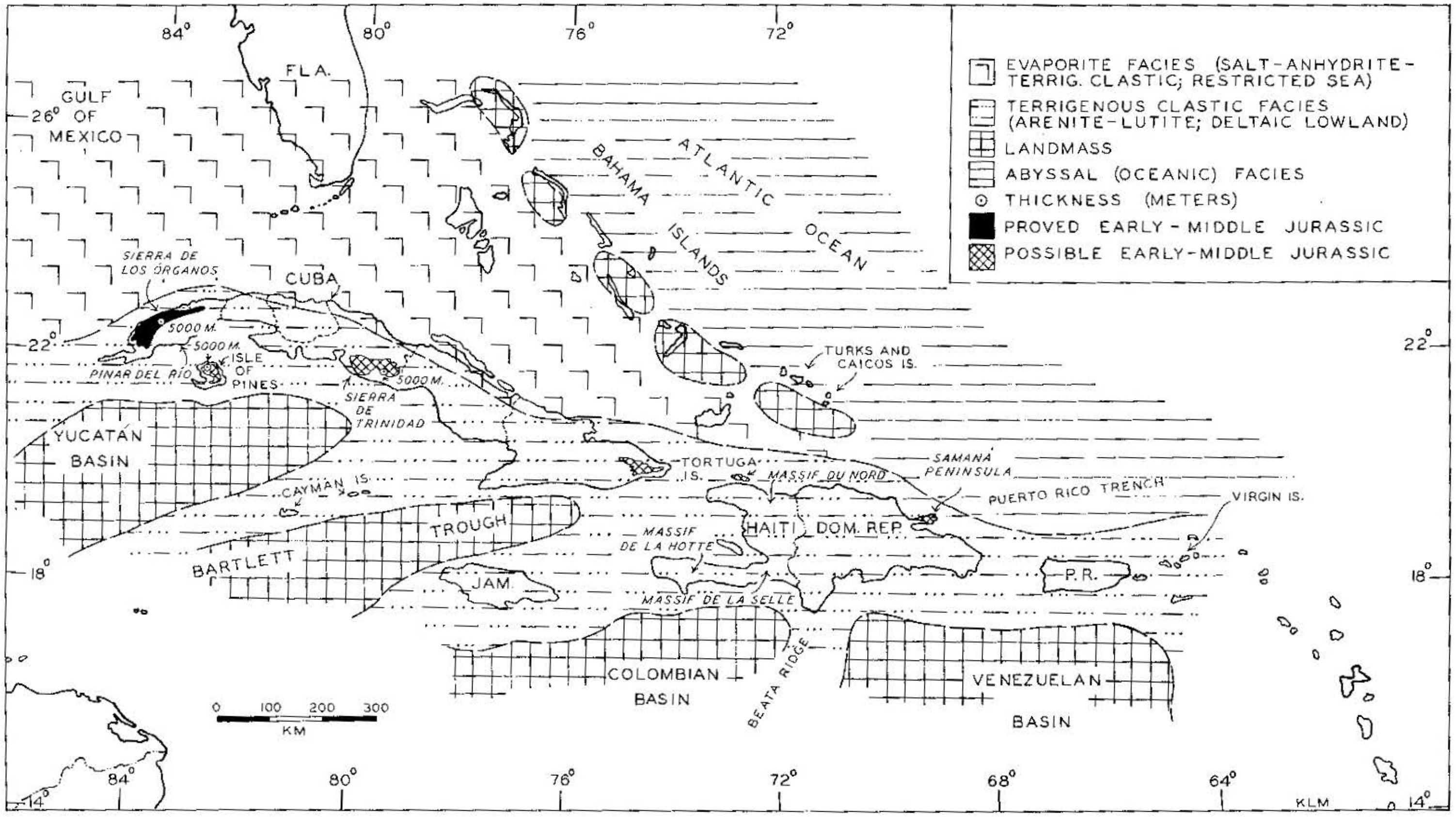

Figure 10. Paleogeography of Greater Antilles during Early and Middle Jurassic, according to Khudoley.

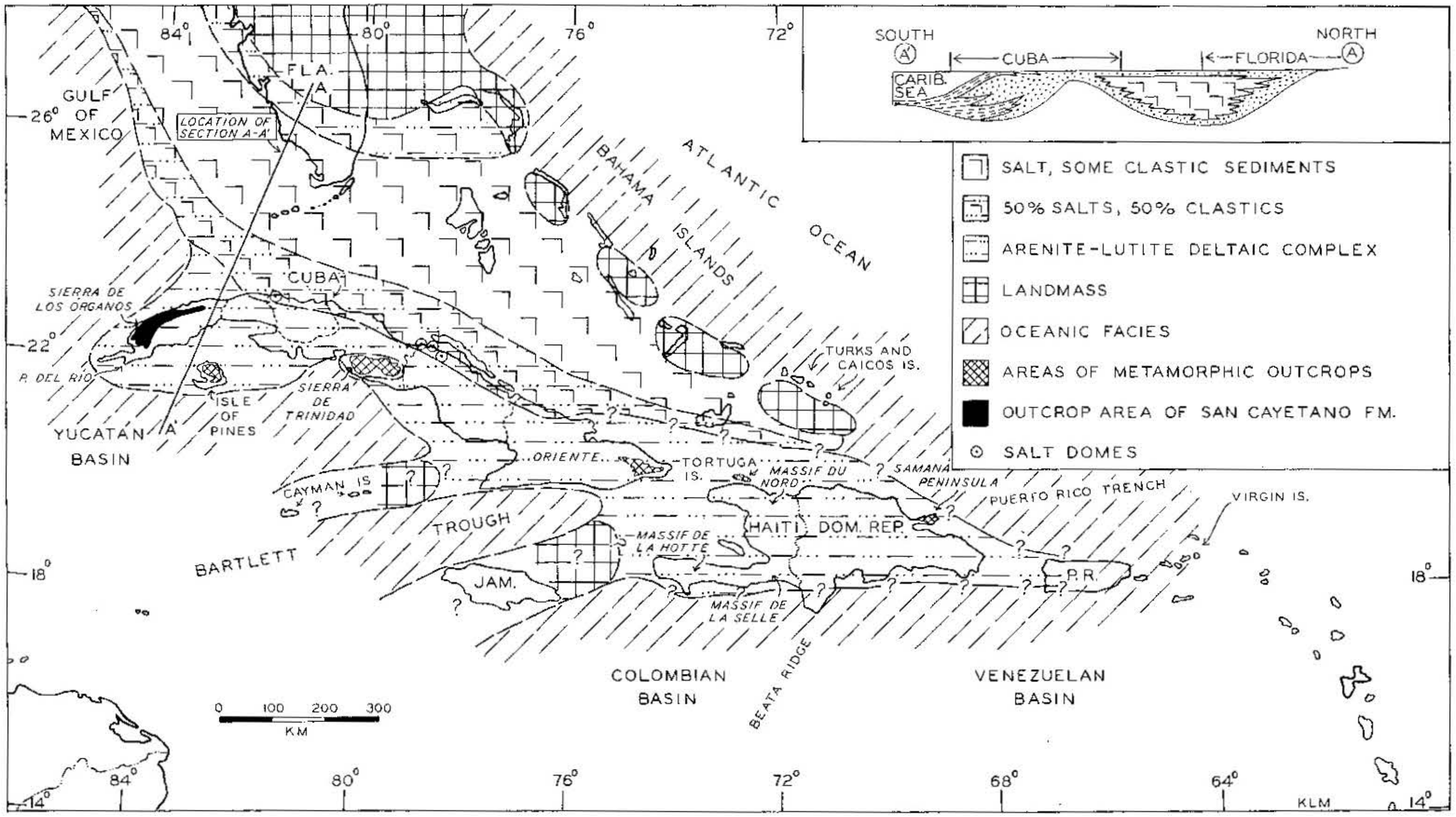

Figure 11.—Paleogeography of Greater Antilles during Early Jurassic through Middle Jurassic (Callovian) time, according to Meyerhoff. Section A-A' shows Meyerhoff's interpretation of relations between Punta Alegre (salt) and San Cayetano Formations.

igneous rocks, silicic gneiss, and other types of metamorphic rocks. The abundance of Ni and Co in the San Cayetano suggests the presence of mafic and ultramafic rocks within the Caribbean landmass.

A lowland or deltaic plain was situated north of the Caribbean landmass on the present site of Cuba (and possibly Hispañola). Numerous rivers, lakes, swamps, and marshes occupied the lowland. The deltaic nature of the San Cayetano rocks supports this interpretation. A rich flora of tropical aspect, the *Phlebopteris cubensis* flora (Vachrameev, 1966), grew on the deltaic plain. From time to time the lowland was transgressed by the sea, as is proved by the presence of marine strata bearing *Inoceramus, Vaugonia, Catinula,* Corbulidae, and other forms (Krömmelbein, 1956; Imlay, 1964).

The deltaic plain was replaced gradually on the north by a shallow marine basin which had only limited connections with the open ocean. The nature of the barrier between the open sea and the basin is unknown, but it may have consisted of Bahama-like islands. In this restricted basin, salt, anhydrite, carbonate, sandstone, and shale accumulated. This shallow evaporitic basin occupied a large area (Fig. 12), including much of the Bahamas, western Florida, southern Alabama, southern Mississippi, Louisiana, southern Arkansas, northeastern and coastal Texas, the Rio Grande embayment, and the Isthmus Saline basin of southern Mexico (Murray, 1966). The existence of diapirs in the Sigsbee Deep also proves the wide extent of this basin (M. Ewing and J. Ewing, 1962; J. Ewing and others, 1962; Nowlin and others, 1965; M. Ewing and Antoine, 1966; Worzel and others, 1968).

Although opinion is divided concerning the presence of a landmass on the site of the present Caribbean Sea, and of a shallow-water basin in what is now the Gulf of Mexico, the conclusion that such was the case seems to be inescapable. The alternative is to postulate, as does Meyerhoff, that the provenance of the terrigenous clastic components of the San Cayetano Formation was the North American continent. Such an alternative is regarded as impossible. The transport of such a great amount of clastic material for such a long distance—and especially through the evaporite basin separating Cuba from North America—seems hardly likely. Bucher (1947, p. 104) also postulated a southern source, and therefore the existence of a Caribbean landmass; perhaps his statement about the San Cayetano Formation expresses this viewpoint most eloquently: "Now it is simply impossible for any such thickness of mud and fine sand to have been spread over the whole floor of the Caribbean Sea. No such quantities of rock can have been removed from the surrounding lands. Such thicknesses accumulate in relatively narrow, local basins between land areas. Although today there is only deep sea around them, there must have been land when these sediments were laid down."

PALEOGEOGRAPHIC RECONSTRUCTION BY MEYERHOFF

If it assumed that the San Cayetano and Punta Alegre Formations are of the same age, Khudoley's argument in favor of a Caribbean source area is reasonable. Meyerhoff *has* made or implied such a correlation in the past

(Meyerhoff, 1964a, 1964b; Hatten and Meyerhoff, 1965; Meyerhoff and Hatten, 1968). However, Meyerhoff now has a different viewpoint which is given in the following paragraphs (Fig. 11, p. 43).

At the end of Paleozoic time, Cuba was subjected to orogeny and in early Mesozoic time was raised above sea level to form a barrier between the present Gulf of Mexico-Bahamas area and the oceanic basin of the modern Caribbean Sea. By Late Triassic or earliest Jurassic time, the sea north of Cuba became a shallow evaporating pan in which thick accumulations of salt and anhydrite collected. The barrier on the east or Atlantic side possibly was, as Khudoley states, a group of islands of the Bahamas type. Minor amounts of terrigenous clastic materials probably were shed into the north Cuban-Bahamas evaporite basin from the exposed Florida craton on the north and from the median welt on the south.

Similar evaporite basins rimmed the northern part of the Gulf of Mexico, the Isthmus of Tehuantepec in southern Mexico, and the Yucatán Peninsula (Meyerhoff, 1967; *see* Fig. 12). The Gulf of Mexico itself probably was an oceanic basin much like that of today, as shown by the seismic (J. Ewing and others, 1960), gravimetric (Dehlinger and Jones, 1965), and magnetometric (Miller and Ewing, 1956; Gough, 1967) data.

During Early Jurassic time, uplift of the Florida Peninsula caused increasing amounts of terrigenous clastic material to be shed southward. Such uplift very possibly was associated with the arching of the Appalachian system after deposition of the Newark Group (Late Triassic). The Florida basement rocks (Applin, 1951; Bridge and Berdan, 1952; Bass, 1969; Milton and Grasty, 1969) are composed of silicic igneous rocks, silicic gneissoid rocks, and other metamorphic rocks of the types required to supply the San Cayetano detritus. Basic to ultrabasic intrusions and flows also are present to account for the high Ni and Co contents of the San Cayetano. By Middle Jurassic time, evaporite deposition was minimal, and terrigenous clastic material was being spread southward from Florida across a great deltaic plain to accumulate as a thick paralic deposit (paraliageosyncline) along the southwestern, southern, and southeastern margins of Cuba. This deltaic plain, near the end of Middle Jurassic time, gradually was transgressed by the sea, as shown by the presence of marine tongues in the upper(?) San Cayetano. After Middle Jurassic time, the sea covered Cuba and encroached steadily northward until all of Florida was the site of marine deposition by Early Cretaceous time.

Supporting this hypothesis are the following: (1) San Cayetano-like inclusions are present in the Punta Alegre Formation; the presence of these terrigenous clastics in the diapirs shows that terrigenous debris was, in fact, being carried into and across at least part of the evaporite basin north of Cuba; (2) the palynologic ages from the diapirs permit a wide latitude for age assignment: that is, Late Triassic through Late Jurassic; more important, however, the age determinations are from the shale inclusions and not from the salt; (3) the detrital mineral suite matches in every detail the mineral suite *known* to be present in the Florida subsurface, so that no vanishing Caribbean landmass need be invoked as a source; (4) Mesozoic quartzitic sedimentary rocks in the

Figure 12. Gulf of Mexico region lithofacies, Triassic to early Late Jurassic (from Meyerhoff, 1967). Shows (1) some of principal positive areas, (2) areas of graben formation and red bed deposition, (3) areas of marine and paralic tongues (mostly Jurassic), (4) coal facies; (5) areas of salt-anhydrite deposition, and (6) areas where volcanics are present. Compiled from various sources, especially Applin (1951), Comité de la Carta Geológica de México (1960), Cortés-Obregón and others (1957), de Cserna (1961), Furrazola-Bermúdez and others (1964), Guzmán and de Cserna (1963), Halbouty (1966), Imlay and others (1948), Marsh (1967), A. A. Meyerhoff and Hatten (1968), Mills and others (1967), Mina (1965), Mixon and others (1959), Murray (1961), H. Richards (1963), Scott and others (1961), and Wall and others (1961).

Greater Antilles are present only in the area south of Florida and the Bahamas; (5) the San Cayetano Formation in the Sierra de los Órganos of Pinar del Río Province grades conformably upward and without significant stratigraphic break into marine Callovian and Oxfordian deposits (Khudoley expresses disagreement with this, as discussed subsequently); (6) vast amounts

of clastic material have been moved by the ancestral Mississippi River system for distances ranging from 1000 to 2400 km from the Rocky Mountains to the present Gulf Coast (Lafayette and New Orleans Geol. Socs., 1968; A. A. Meyerhoff, 1968; Paine and Meyerhoff, 1968), yet the distance from *known* Florida basement to San Cayetano outcrops in Cuba is only 700 km. Since early Pliocene time alone, these lengthy rivers of the Mississippi system have deposited from 3000 to 6000 m of sediment along the northern margin of the Gulf of Mexico; the thickness of the San Cayetano Formation probably is less than 5000 m; (7) marine beds are increasingly numerous from Callovian(?) to Early Cretaceous time, each successive unit being more marine and more extensive than the preceding unit; and (8) Edgar's (1968; *see also* J. Ewing and others, 1967) geological-geophysical study of the Caribbean area suggests that this sea has been in existence since middle Mesozoic or late Paleozoic time. Edgar's reasoning is that the "B" reflector in the Caribbean Sea may be correlated with either the β or B reflector of the western North Atlantic (J. Ewing and others, 1966; M. Ewing, 1965; Saito and others, 1966; Habib, 1968a). Edgar's correlation of "B" with β or B (β is a reflecting horizon above B) is based on the fact that the overlying "A" reflector is at or close to the Cretaceous-Tertiary boundary, as proved by the presence of early Eocene deep-sea faunas in samples collected at or just above the "A" reflector where it crops out adjacent to the Beata Ridge. In the western North Atlantic, a reflector in a similar position, reflector A, crops out and samples collected close to its outcrop are Maestrichtian (latest Cretaceous: J. Ewing and others, 1966; Saito and others, 1966). Samples from β are Aptian-Albian (Early Cretaceous: Habib, 1968a). Therefore, if β or B of the North Atlantic correlates with "B" of the Caribbean, "B" is Early Cretaceous or older (recent drilling by the *Glomar Challenger* east of the Bahamas has revealed the presence of deep-sea Tithonian sediments beneath the β reflector). The thickness of sediment above "A" is 480 m; that between "A" and "B" is 540 m thick; and that below "B" is 1000 m thick. By projecting depositional rates calculated from the intervals "A" to surface, and "B" to "A," one may deduce a minimum age of Triassic on the Harland and others (1964) time scale. If sediment compaction is taken into account, the age of the Caribbean Sea floor is much older than Triassic. During 1970–1971, drilling by the *Glomar Challenger* in the deep Caribbean revealed the presence of basaltic crust beneath the sedimentary cover. Thus, the concept of a "foundered" continent is no longer tenable. However, "oceanization" is not ruled out.

Additional and related support for Meyerhoff's hypothesis advanced here is from other geological considerations. (1) Fox and others (P. J. Fox, October 9, 1968, written commun.) collected a deep-water Maestrichtian fauna at 17° 58.8′N., 73°22.0′W., off the slope south of Haiti. (2) W. R. Bryant (*in* Meyerhoff, 1967, p. 229) postulated that the Sigsbee Knolls of the Gulf of Mexico are salt diapirs of the southern Mexico Saline formation (gypsum- and anhydrite-bearing cap rock was drilled on one of the diapirs during 1968 by the *Glomar Challenger*). Bryant postulated that this salt was squeezed from

beneath the Yucatán Peninsula as the sedimentary overburden on the peninsula increased. This seemingly radical explanation is strongly supported by the fact that the known diapirs of the deep part of the Gulf of Mexico parallel very closely the 3600 m bathymetric contour around the western and northwestern sides of the Yucatán Peninsula, and several diapiric intrusions have been found north of Yucatán (Antoine and Bryant, 1969). Moreover, salt is moving laterally into the Gulf of Mexico at the Sigsbee scarp (M. Ewing and Antoine, 1966; Amery, 1969), so that Antoine and Bryant's hypothesis has a basis in fact from events elsewhere in the Gulf of Mexico basin. (3) Jux (1961) determined a probable age for the Louann Salt of Texas and Louisiana of Rhaetian (latest Triassic)-Early Jurassic. Although not conclusive, Jux's dates are older than the definitely dated strata of the San Cayetano (Middle Jurassic). (4) In both the northern and southern parts of the Gulf of Mexico basin, the Louann Salt and its probable equivalent, the Saline formation of southern Mexico (Contreras and Castillón, 1968), are separated from younger marine deposits by a clastic wedge: the "Lechos Rojos" of the Isthmus of Tehuantepec and the Norphlet Formation of the northern Gulf of Mexico. (5) East of the Dominican Republic (that is, away from the proximity of the continental areas of the Bahamas and Florida), the entire Cretaceous-middle Eocene eugeosynclinal section is derived from local source areas (Donnelly, 1964, 1966a; Rogers and Donnelly, 1966) and the section is almost quartz-free throughout the Cretaceous section (H. A. Meyerhoff, 1933; Mattson and Glover, 1960). This fact indicates that no continental landmass was nearby to provide quartz detritus. (6) Rogers and Donnelly's (1966) study of uranium and thorium abundances in eugeosynclinal sequences shows, for the eastern Greater Antilles, that the amounts of these elements present are typical of depositional basins removed from continental areas. They concluded, therefore, that the only source areas for materials with such low uranium and thorium abundances had to be the oceanic crust and mantle.

A more theoretical consideration which indicates that the Caribbean Sea and Gulf of Mexico were underlain by oceanic crust during their entire history involves the thermodynamic reactions involved if the process of basification can take place. A "granitic" crust overlying a "basaltic" layer and an ultramafic upper mantle is, generally speaking, a stable chemical system (Turner and Verhoogen, 1960, p. 35–40), provided that pressure and temperature do not change. For "basalt" crust to absorb "granite" crust, the "basalt" would have to reach temperatures in the order of 1000°C across a large area, or several hundred degrees higher than the 1000°C isotherm at a depth of 35 to 40 km (average thickness of continental crust). Furthermore, a chemical imbalance would result which probably is impossible, no matter what physical conditions are assumed (Lustig, 1959). In view of the fact that rocks 2.7 b.y. and even 3.0 b.y. old comprise the exposed crust in large areas of the USSR, Canada, Africa, and elsewhere, it is difficult to understand why these shield areas never have been basified. Moreover, if areas such as the Caribbean and the Gulf of Mexico once had been continents, the Paleozoic-Jurassic faunal

distributions of North and South America would be much different from what they actually are.

Nevertheless, what Rogers and Donnelly (1966, p. 134) have called the "myth of a Caribbean continent" persists in arguments propounded by numerous geologists—including a co-author of this paper—who have worked in the Caribbean-Gulf of Mexico region. Butterlin (1956) strongly advocated the existence of a Caribbean continent, and more recently (1968), he wrote that the presence of andesite, dacite, and quartz diorite in the Lesser Antilles arc demonstrates the proximity of silicic crustal sources for magmas of these compositions.

Butterlin's views are not tenable in view of the work by Dickinson and Hatherton (1967) and Dickinson (1968) on the origin of andesite, and the experimental study of the origin of granodioritic rocks by Wyllie and Tuttle (1961). Butterlin maintained that andesitic rocks form close to continents but do not form in wholly oceanic regions removed from continents. Butterlin neglected the most important fact of all: andesite forms in island-arc regions where Benioff zones extend 150 to 700 km into the mantle; fracture zones of such depth do not occur in ocean basins away from island arcs. Dickinson and Hatherton (1967) and Dickinson (1968) recognized this fact and correlated andesite occurrence, and even variations in andesite composition, with depths of Benioff zones beneath the volcanic chains of island arcs.

Wyllie and Tuttle (1961) refuted the Butterlin type of argument by demonstrating in the laboratory that shales, including those derived exclusively from a mafic-volcanic (eugeosynclinal) terrane, melt to form rocks of granodioritic to granitic compositions. At pressures of 1000 to 2000 atm, and temperatures of 670°C to 740°C—with or without the presence of water—shale melts to form a silicic magma. Wyllie and Tuttle concluded that sedimentary rocks can be melted at no great depth in orogenic belts, and that ". . . the root of 'the granite problem' is buried not only beneath mountain ranges, but also in geologists' choice of words" (p. 65).

With regard to the problem of the origin of the San Cayetano Formation in Cuba, if Khudoley's correlation of the San Cayetano with the Punta Alegre should turn out to be correct, the possibility also must be considered that the San Cayetano was derived from uplifts of Paleozoic rocks in Cuba itself (that is, Jarahueca fenster-median welt area, Sierra de Trinidad, Isle of Pines, and so on: Rigassi, 1963, p. 347). Although it has seemed implausible to many geologists, rapid erosion of closely adjacent highlands commonly provides extensive accumulations of sediments which are several thousand meters thick (for example, the Newark Group of eastern North America). The fact also should be mentioned that the extent of the San Cayetano Formation shown on Figures 10 and 11 is very speculative, considering the limited areas of outcrops of this formation and the lack of adequate dating of rocks assigned to the formation. Thus, a great volume of rocks may not be involved, and local sources might easily have provided the sediments which comprise the San Cayetano.